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Aquaculture and the environment: the supply of and demand for environmental goods and services by Asian aquaculture and the implications for sustainability

M C M Beveridge
Institute of Aquaculture, University of Stirling, Stirling, Scotland

M J Phillips
Network of Aquaculture Centres for Asia, Bangkok, Thailand

D J Macintosh
Centre for Tropical Ecosystems, University of Aarhus, Aarhus, Denmark

Correspondence: Dr M C M Beveridge, Institute of Aquaculture, University of Stirling, Stirling, Scotland FK9 4LA, United Kingdom (Fax: + 44 1786 451462; E-mail: mcmb1@stir.ac.uk)

Abstract

The present paper explores the relationships between aquaculture and the environment in Asia, focusing on the demands for environmental goods and services among different sectors. Aquaculture in the region accounts for 88% of global production by weight and 80% by value. Nevertheless, environmental problems are increasingly apparent and the higher the demands for environmental goods and services, the more negative the impacts.

Against a background of rapid social, economic and political change, the paper considers how the sustainability of the industry is best assured. An integrated view of resource use, in which aquaculture is but one activity, is necessary for sustainable development. The roles of planning, education, research and environmental management schemes are discussed.

Introduction

Production of farmed fish and shellfish in Asia has increased threefold in 10 years, from just over 5 million tonnes in 1984 to 15 million tonnes in 1994 (FAO 1996). Excluding seaweeds, aquaculture in the region now accounts for 88% of global production by weight and 80% by value (US$ 24 billion) (FAO 1996). Nevertheless, the sustainability of some aquaculture industries are increasingly being questioned: irrespective of which indicators are used – resource use efficiency, financial viability, operational period, social interactions – sustainability issues are readily apparent throughout the region. Whilst the concepts of sustainability are poorly defined for aquaculture, the consensus is that sustainability incorporates social, technical, financial and ecological concerns and that interactions between aquaculture and its ecological environment – the focus of this paper – are becoming increasingly important and the extent of the problems are such that they can no longer be ignored. As an example, the Network of Aquaculture Centres in Asia (NACA) estimates that environmental problems (including disease losses) cost the sector in Asia at least US$ 3 billion per annum in lost revenues (ADB/NACA 1996).

The present paper explores the relationships between aquaculture and the environment in Asia, focusing on the demands for environmental goods and services. Against a background of rapid social, economic and environmental changes, the paper also considers how the sustainability of the industry is best assured.

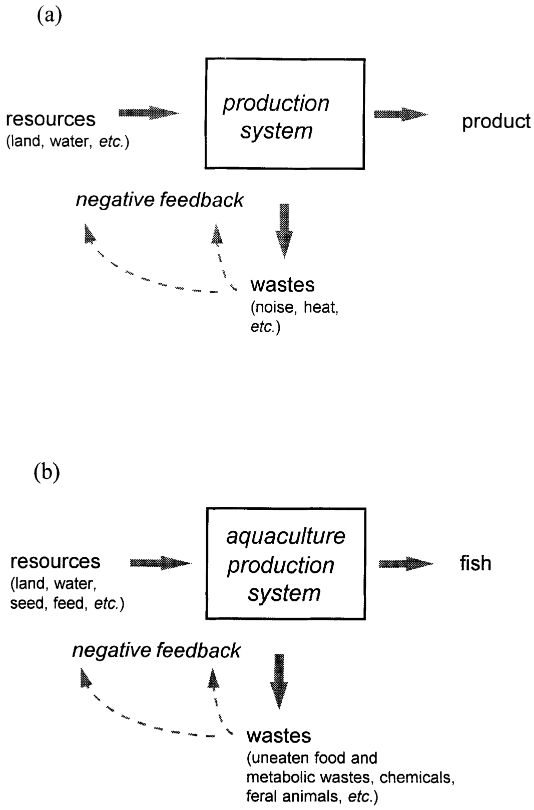

Figure 1 The relationship between (a) economic activities and the environment and (b) aquaculture and the environment (see text).

Relationships between aquaculture, the environment and sustainability

Aquaculture is reliant on a wide range of natural resources or environmental goods (Fig. 1), including space or land to site an aquaculture operation, materials (timber, steel etc.), for construction of the aquaculture system and ancillary facilities (roads, offices etc.), water to support the animals, seed (larvae, postlarvae, fry) for stocking and feed and/or fertilizers for the enhancement of production. Because production is largely from ecologically open systems, in which materials are imported to the production site and transformed into marketable products through the use of energy, wastes are inevitably produced (Folke, Kautsky & Troell 1993). Wastes include not only uneaten food, faecal and urinary products but also chemotherapeutants, feral (escaped) animals and pathogens which may find their way into the environment. Aquaculture is also dependent upon the environment for essential services: the replenishment of oxygen and the dispersal and assimilation of wastes which otherwise would accumulate in the production system, exerting negative feedback on fish growth and survival.

Thus, factors that determine the supply of environmental goods and services, such as changes in land use and pollution, may adversely affect aquaculture. Aquacultural impacts on the environment stem from the consumption of environmental goods, the transformation (i.e. farming) process itself and from the production and release of wastes, the overall relationship ranging from the positive (i.e. enhancement of environmental quality) through the relatively neutral, to that which results in environmental degradation. In general, the higher the demand for ecological goods and services, the more negative the impacts on the environment.

Inland aquaculture and the environment

Around 85% of all fish and crustacean culture in the region is in inland waters (FAO 1996). Most comes from semi-intensive ponds, only 5–10% being from cages and pens (ADB/NACA 1996). The most important farmed species are Chinese and Indian major carps and common carp (*Cyprinus carpio* L.), tilapias and catfish accounting for much of the rest.

Inland pond aquaculture is largely confined to agro-ecosystems, utilizing local supplies of surface or groundwater. Ponds enhance habitat and landscape diversity within agro-ecosystems and by and large, pond culture remains integrated with other aspects of the rural social, economic and natural environments (Beveridge & Phillips 1993; Edwards 1993); indeed, in the most highly integrated systems, fish ponds play a pivotal role in supporting other activities and in water conservation (Pullin & Prein 1995). Production is relatively efficient, being based on the use of agricultural fertilizers and locally available crop and/or animal production by-products. Unlike mariculture, seed is largely from hatcheries. Most wastes are confined to the pond except, perhaps, during harvesting (Beveridge, Phillips & Clarke 1991; Beveridge & Phillips 1993), and can often be readily utilized in the production of other crops. Such systems are being avidly promoted by various organizations, and are recognized in the UNCED Agenda 21, as highly appropriate and important contributors to environmental improvement under the right conditions.

While such farms at present pose little threat to the environment, there are certain issues that are becoming important: water is one. Although water use is largely limited to counteracting evaporative and seepage losses, there is a growing shortage of water in relation to industry, domestic and agricultural demand in some areas (e.g. noted in some parts of Vietnam, China and India by FAO/NACA 1995). With increasing population densities in the region and human intervention changing the pattern of water distribution, coupled with increasing intensification of both agriculture and aquaculture production, conflicts for water resources may increase and increasing attention will be required to ensure aquaculture contributes in a positive way to water conservation and quality improvement, and is well integrated into both farm-level and watershed water resource management.

Inland water cage fish farms are usually sited in multipurpose, publicly owned water bodies which are exploited for food and/or relied upon to dissipate and assimilate wastes. Cage farms are rarely integrated to the same degree as ponds. While many farms are initially heavily dependent on the supply of natural food, there tends to be an increasing reliance on supplemental foods and a reduction in profitability with time (Beveridge 1984, 1996; Sevilleja, Manalili & Guerrero 1993; Santiago 1995). By comparison with marine environments, lakes and reservoirs are small, have poor currents and exchange times of months and years rather than days. Waste production can be high: estimates from an intensive cage tilapia farm in Lake Kariba, Zimbabwe, are comparable to those from intensively reared salmonids in temperate regions (Troell & Berg 1997). Cage farms in lakes and reservoirs are thus vulnerable, both to general pollution and to self-inflicted water quality-related problems, and conflicts with other resource users (Beveridge 1984, 1996; Beveridge & Muir 1997). Fish cages in Sampaloc Lake (Philippines), in Shuimotan Reservoir (China) and in the large World Bank-funded development projects in Cirata and Saguling reservoirs (Indonesia) are examples where mass mortalities of stock have occurred because of overexploitation of the capacity of the systems to provide dissolved oxygen and to disperse and assimilate wastes (Costa-Pierce 1992; Lu 1992; Santiago 1995; C. Kwei Lin, AIT, Bangkok, personal communication). While uncontrolled lakeside developments may have played a role (as argued by Costa-Pierce 1992), nonetheless with increasing production and intensification of production methods, oxygen demand in both the hypolimnion and epilimnion grows (Fig. 2), increasing the risk of fish kills resulting from the upwelling of anoxic hypolimnetic waters during mixing.

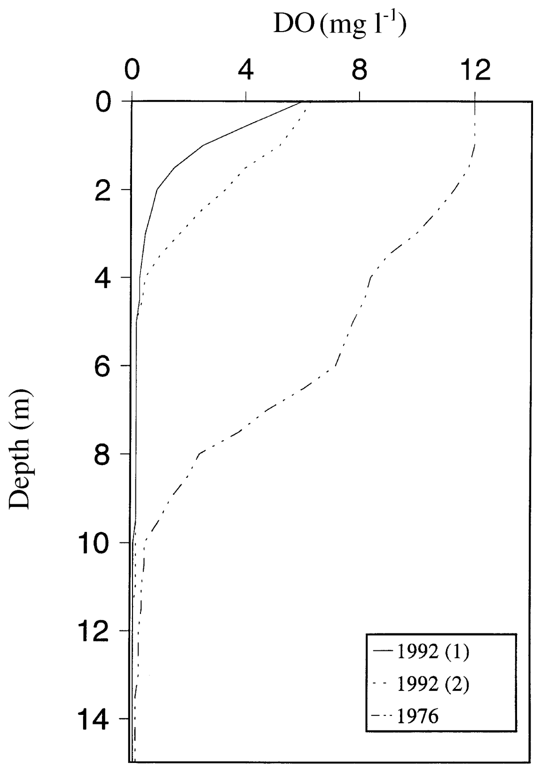

Figure 2 Dissolved oxygen vs. depth profiles, Sampaloc Lake, Philippines, before and after (sites 1, 2) the development of cage aquaculture (redrawn from Santiago 1995).

Another important issue which will receive increasing attention is the role of exotic species and the use and transfer or introductions of genetically modified organisms (GMOs). Inland aquaculture in the region, both cage and pond based, has also been heavily dependent upon exotic species and strains (Welcomme 1988; De Silva 1989; Pullin 1994). Captive aquatic animals inevitably escape and can colonize natural waters: an estimated two thirds of species introductions in tropical inland waters have become established (Welcomme 1988), although many are considered to have had positive socio-economic benefits. Among the risks posed by feral species and strains are habitat destruction, elimination of local species/strains by competition or predation, and genetic degradation of local stocks, all of which result in loss of biodiversity (Welcomme 1988; Beveridge, Ross & Kelly 1994; Ross & Beveridge 1995). In fact, there has been little study of environmental and socio-economic impacts of introductions and translocations in the region, and while the recent FAO/NACA survey reports adverse impacts related to the introduction of the African catfish *Clarias gariepinus* (Burchell), tilapias and silver carp (FAO/NACA 1995), conclusions drawn must be interpreted with care as they depend upon criteria used, time frame and a degree of subjectivity (Welcomme 1988). In contrast, the increased awareness of potential problems associated with exotic fish introductions is giving impetus to research on use of exotic fish species. In Cambodia, for example, recent work has focused on the potential for culture of the indigenous giant carp, *Catlocarpio siamensis* Boulenger, and other local species. There is an urgent need for review of strategies associated with the use of exotics and GMOs for aquaculture and the further development of practical codes for risk assessment and management, as emphasized in the FAO Code of Conduct for Responsible Fisheries (FAO 1997), and as attention focuses on implementation of strategies/actions by signatories to the Convention on Biological Diversity.

Coastal aquaculture and the environment

In terms of resource use, economics and employment, coastal aquaculture in Asia is dominated by mollusc, seaweed and shrimp culture. The pond production of *Penaeus monodon* Fabricus, *P. chinensis* Osbeck, *P. merguensis* De Man has increased dramatically from 100 000 t in 1984 to 650 000 t in 1994 (FAO 1996). Increases have been achieved through intensification, extensification in some countries and increases in number of farmers involved. Shrimp farming is heavily reliant on environmental goods and services, as is evident from ecological footprint and energy use studies (Larsson, Folke & Kautsky 1994; Kautsky, Berg, Folke & Troell 1997). The industry is an important consumer of coastal land, especially agricultural land and mangrove forest (see elsewhere this volume; also Primavera 1991, 1993; Macintosh & Phillips 1992; Phillips, Lin & Beveridge 1993; Larsson *et al.* 1994; Parks & Boniface 1994; Phillips 1994, 1995). Ponds in some areas have been abandoned after only a few years, leaving behind land that may be difficult and costly to rehabilitate. Loss of agricultural land has obvious economic impact. Mangrove losses, too, have important but less immediately tangible economic impacts in terms of decreased timber and fisheries yields and exacerbation of coastal erosion, some of which may outweigh short-term benefits of shrimp farming (Primavera 1991, 1993; Phillips *et al.* 1993; Larsson *et al.* 1994). Fortunately, there is increasing recognition of the ecological benefits of mangroves and their general unsuitability as sites for intensive shrimp farming, and it is likely that use of mangroves for shrimp farming in future will decrease.

As a result of domestic and industrial pollution and poorly regulated growth of the shrimp farming industry itself, supplies of good-quality water in some areas have become difficult to secure. Water use is greatest among intensive farmers, although there is a trend towards reduced water exchange (so as to minimize disease risks) which is drastically reducing effluent loads to coastal waters in some countries (Phillips 1995; ADB/NACA 1996). The increasing trend towards 'zero discharge' systems should lead to improvements in water quality. Movement of sea water has caused damage to nearby crops, leading to social conflicts in some areas of South Asia and elsewhere (Bundell & Maybin 1996).

Shrimp farming remains largely dependent upon wild-caught seed or gravid females, a trade which has environmental implications. Catches of wild postlarvae and gravid females are in decline in some areas (Silas 1987; Banerjee 1993; Phillips 1995). Demand for shrimp broodstock and seed often outstrips supply so that movements of animals (including exotic strains and species) within and between countries, with implications for spread of disease, can occur. However, it is impossible to attribute the decline in catches solely to the development of shrimp farming, given changes in fishing pressure and gear size and environmental degradation. The majority of shrimp production relies on intensive diets, around 1 million tonnes of which were used in 1994, derived from some 2.5 million tonnes of fish plus other fish products. This is equivalent to nearly 10% of global fish landings used for fish meal and fish oil production (Tacon 1995). With world fish meal production steadily declining and with animal – including aquatic

Table 1 Nutrient budgets for semi-intensively and intensively managed 1 ha shrimp ponds, based on data collected from Thai farming practices (Phillips 1994). Waste nutrients end up either in the pond or in the environment

	Semi-intensive	Intensive
Production per harvest (t)	1.0	9.0
Production year^{-1} (t)	3.0	27.0
Food conversion ratio	1.4 : 1	2.0 : 1
Nutrient inputs in food (t year^{-1})		
Nitrogen	2.98	38.3
Phosphorus	0.45	5.83
Nutrients removed in shrimp harvest (t year^{-1})		
Nitrogen	2.66	23.99
Phosphorus	0.18	1.59
Waste nutrient loadings (kg year^{-1})		
Nitrogen	29	1434
Phosphorus	27	424
Waste nutrient loadings (kg per t shrimp harvested year^{-1})		
Nitrogen	9.7	53.1
Phosphorus	9.0	15.7

Table 2 Effluent characteristics (mg l^{-1}) of Thai shrimp ponds (study 1 – Phillips 1994; study 2 – Briggs & Funge-Smith 1994). Data on domestic sewage (Phillips 1994) are included for comparison

	Shrimp pond effluent		Domestic waste water		
	Study 1	Study 2	Untreated	Primary treatment	Secondary treatment
BOD_5	4.0–10.2	7.4–8.4	300	200	30
Total-N	0.03–5.06	2.19–3.45	75	60	40
Total-P	0.05–2.02	0.27–0.40	20	15	12
Solids	119–225	120–165	500	–	15

animal – production intensifying, the implications for shrimp farming are increasing feed prices.

Extensive shrimp farming methods produce little waste, although newly constructed ponds built on acid sulphate soils can discharge highly acidic water (Phillips *et al.* 1993). With intensification, however, comes higher stocking densities and greater use of water, feeds and fertilizers, leading to increased waste production (Table 1). Briggs & Funge-Smith (1994) estimate that 40% of nitrogen and 90% of phosphorus wastes from intensively managed Thai shrimp ponds are trapped in the sediments while 44% of waste nitrogen and 11% of waste phosphorus are released during routine water exchange (two thirds) and harvesting (one third). Sediment-bound nutrients are dried and removed either mechanically or by high-pressure hose (Phillips 1995). Studies by Zieman, Walsh, Saphore & Fulton-Bennett (1992), Briggs & Funge-Smith (1994) and Robertson & Phillips (1995) suggest that routine effluent discharges are dilute (Table 2) although those discharged during cleaning have much higher concentrations. Negative impacts from effluents can easily be controlled, however, by use of settling ponds.

Chen & Shang (1992), Corea, Jayasinghe, Ekaratne & Johnstone (1995) and Bundell & Maybin (1996) report numerous instances of localized deterioration of water quality attributable to discharge of shrimp farm wastes. However, evidence for wide-scale environmental damage, even in heavily farmed areas, is slim. Evaluation of the causes of environmental deterioration in Bohai Bay, China, suggests that the fraction of BOD and COD contributed by the 86 000 ha of shrimp ponds was $< 5\%$ of total loadings, $> 95\%$ being derived from industrial and domestic sources (FAO/NACA 1995). Nevertheless, self-pollution has been an important contributory factor in the decline of shrimp farming in many areas.

Although the use – and hence release – of chemicals in aquaculture is much less than in agriculture, and many of the chemicals used are not harmful to the environment (e.g. lime), there has been particular concern about antibiotics. The use and sometime abuse of antibiotics in more intensive farming has led to multiple drug resistance among pathogens and occasional rejection of Asian farmed shrimp by importing countries (Aoki 1992; Baticados & Paclibare 1992). As awareness of public health and food safety aspects increases, concerns about the possible transfer of resistance to human pathogens (Alderman & Michel 1992) are likely to grow.

Some 700 000 t of marine fish are produced in farms in Asia. Production is largely of two species: milkfish (*Chanos chanos* (Forsskål); 400 000 t) and yellowtail (*Seriola quinqueradiata* Temminck & Schlegel; 140 000 t), with limited but increasing quantities of sea bream, *Pagrus major* (Temminck & Schlegel), sea bass, *Lates calcarifer* (Bloch) and groupers, *Epinephelus* spp. (FAO 1996). Most species, with the exception of milkfish and mullets, are reared by intensive means in cages in sheltered inshore coastal areas. While there have been few studies of the relationships between cage production systems and the environment in the coastal tropics, the principles are well understood from studies elsewhere. Impacts stem from the consumption of environmental goods, especially seed and feed, and from the production and release of wastes – uneaten food, faecal and urinary wastes, chemotherapeutants and feral animals.

Marine fish culture of many species in the region remains largely dependent upon wild seed, spawning in captivity being either technically difficult or is uneconomic although production of hatchery-reared milkfish in Indonesia and Taiwan has been steadily increasing. The seed collection and transport of some species may also be wasteful. Despite the fact that increasing shortages of wild fry are reported (FAO/NACA 1995), impacts of collection on wild populations are unquantifiable because of overfishing and habitat destruction and pollution. It should also be recognized that collection of wild fry and fingerlings provides an important industry for small-scale fishermen in countries such as Indonesia and the Philippines. Some 200 000 to 250 000 t of marine fish are reared by intensive methods in the region, the majority of production still relying on fresh fish rather than pelleted feeds (New, Tacon & Csavas 1993). At an estimated average food conversion ratio of 7:1, around 2 million tonnes of locally caught fish are used. Although some have suggested there may be consequences for local stocks and human food, the quantities used are likely to be insignificant in terms of overall fisheries production.

Studies carried out in Hong Kong indicate that 85% of phosphorus, 80–88% carbon and 52–95% nitrogen inputs to marine fish cages may be lost through uneaten food, faecal and urinary wastes (Wu 1994). Wastes per unit production are higher than from intensive cage salmonid farming, in part because trash fish losses are around 20–38% compared with around 10% for pelleted feed used in Europe (Wu 1994; Beveridge 1996). While soluble wastes appear to be rapidly dispersed, leaving little apparent impact other than in the immediate vicinity of the farm, fish farm wastes have been shown in laboratory studies to stimulate growth and production of dinoflagellates (Nishimura 1982). Waste food and faecal matter sediment, under and around cages, causes changes in sediment structure and function. Anoxic sediments, devoid of macrobenthos, are readily apparent below cages, while sediments immediately outside the cage area tend to be colonized by high numbers of opportunistic macrobenthic species. However, the area affected may be higher than in temperate marine cage culture (Wu 1994) because of the much higher levels of waste feed and because the uneaten trash fish is less dense and is dispersed over a greater area. The total area affected in coastal areas where marine culture is practiced is insignificant at present.

Despite some disease problems, few chemotherapeutants are used. When used, they are applied either as in-feed medicines (antimicrobials) or bath treatments (parasiticides), excess chemicals and breakdown products being released into the environment. Antimicrobial compounds can inhibit microbial functioning in sediments, induce multiple resistance to drugs among microbial communities and enter the human food chain, although impacts are highly compound- and site-specific (Weston 1996), while parasiticides, such as dichlorvos, are highly toxic to crustaceans. Tributyl-tin-based antifoulants, widely proscribed elsewhere, are still occasionally used in Asia despite well-documented risks to marine life (Davies, Drinkwater & McKie 1988). There have been no studies of escaped fish or their impacts. The absence of research has fuelled speculation that feral animals may adversely affect fish communities. However, this is unlikely as most farmed marine species are indigenous, and, because marine fish eggs are pelagic, impacts are likely to be small by comparison with impacts in inland waters (Beveridge *et al.* 1994, 1997). Aquaculture of some marine groupers and coral reef-associated species is also being promoted as a means of reducing pressures on wild stocks.

As much as three-quarters (3 million tonnes) of the world's farmed molluscs and 95% (5 million tonnes) of world aquatic plant production comes from the region. Farmed molluscs filter seston from the water column and as they are net removers of nutrients, farmed molluscs may be seen as beneficial to coastal water quality. Although they can contribute to water quality improvement in coastal waters, they can also cause localized biodeposition of pseudofaeces, which can have impacts similar to those of wastes deposited under marine cage farms (Folke & Kautsky 1989). It has also been reported that heavy metals, removed from the water during filter feeding and deposited in pseudofaeces, can accumulate in sediments and damage macrobenthic communities. Moreover, if sufficiently crowded, farmed molluscs can exert heavy predation pressure on the plankton community which modifies food web structure (Barg 1992; Beveridge, Ross & Stewart 1997). Of greater concern than the impacts of mollusc culture on the environment is the increasingly serious impact that deteriorating coastal water quality in the region is having on mollusc farming and production potential. This is of particular concern given the potential for molluscs to supply protein-rich food for poorer sectors of society. Mollusc beds can be smothered by siltation resulting from changes in land use and in hydrological regulation of rivers (e.g. Malaysian country report, FAO/NACA 1995). Moreover, because of their filter-feeding habit, molluscs can accumulate pollutants, toxins from red tide organisms and pathogenic microorganisms. The increasing frequency of red tides in the region has resulted in numerous outbreaks of paralytic shellfish poisoning and other disorders, leading to reports of illness and occasional deaths (Maclean 1993).

Seaweed culture is associated with few environmental problems (Phillips 1990); indeed, by removing nutrients it may help combat coastal eutrophication. Although anthropogenic loads of nutrients can increase seaweed growth, algal blooms promoted by hypernutrification can damage seaweed farms (Maclean 1993), while heavy metals and other industrial chemical discharges have caused localized contamination of seaweeds in Philippines and China (FAO/NACA 1995). While seaweed farming has only proven a problem where lack of effective planning has permitted extensive areas, or environmentally sensitive sites, to be developed (Phillips 1990), species translocations may become an important issue.

Aquaculture and the environment: a perspective for sustainable development in the region

It is clear that aquaculture and the environment are inextricably linked and that aquaculture is unsustainable where there is overexploitation of environmental goods and services, irrespective of whether overexploitation is self-inflicted or arises from competition for resources with non-aquaculture users. These facts, and the fact that demands increase with intensification, are increasingly being incorporated into policy and are even of growing concern to farmers.

While risks to sustainability seem to be greatest in intensive, large-scale operations (e.g. intensive shrimp and cage culture), population growth, intensification of agriculture and industrialization all result in increased consumption of the same environmental goods and services that aquaculture requires. Hence, even extensive aquaculture operations, such as mussel and oyster farming, are vulnerable. Sustainability issues need to be fully integrated within the development process for all types of aquaculture.

Because of the complex interactions between different activities at the environmental, social and economic levels, an integrated view of resource use, in which aquaculture is but one activity, is necessary for sustainable development. The OECD, among others, see governmental intervention as essential for the efficient and sustainable management of resources (OECD 1993). However, public consensus and participation in decision making are also essential if conflicts are to be minimized and if satisfactory compromises are to be made in the allocation of natural resources among potentially competing groups. Appropriate decisions can only result if people are educated about the environment and are empowered to participate in the development process. The severe and increasing pressures on the coastal zone arising from urbanization, pollution, tourism, etc. have resulted in ever more states and regions adopting integrated coastal zone management (ICZM) programmes (Sorensen 1993), a trend readily apparent in Asia. The undoubted vulnerability of inland waters and the growing awareness of the interconnectedness of human endeavours at this geographical scale has also resulted in the catchment being gradually adopted as the natural management unit for inland waters (Chandler 1994). Integrating aquaculture with other aspects of the rural economy, especially agriculture, offers the greatest opportunities for reducing the dependence on external resources and the impacts associated with the release of wastes (Folke & Kautsky 1989; Chua 1993; Berg, Michelsén, Troell, Folke & Kautsky 1996).

Implementation of ICZM and integrated catchment management is recognized as a problem, which in large measure has occurred because of the absence of adequate policies and because of legislation and institutional problems, such as the lack of unitary authorities with sufficiently broad powers and responsibilities. Environmental impact assessment (EIA) can assist in evaluating options and indeed is increasingly being used to plan coastal aquaculture developments in western Europe. However, sound information upon which to base decisions is required and research, both fundamental and applied, is urgently needed. There is still a lack of understanding of functioning of ecosystems or how they respond to perturbation. Environmental capacity models developed for use in fresh waters, while useful, must be used with care and require further development (Kelly 1995; Beveridge 1996). Organic waste dispersion models for the marine environment are widely used in North America and Europe (Hargrave 1994). However, assimilative capacity models are still being developed, measurements of organic matter decomposition in sediments under fish cages in the Gulf of Aqaba suggesting that the capacity of sediments may be 3–4 times greater in warm than in temperate waters (Angel, Krost, Zuber, Mozes & Neori 1992). Moreover, it is debatable whether benthic capacity models are applicable in highly enclosed coastal bays; here, water quality models may be more appropriate.

In Asia the coastal zone has undergone a period of rapid development, resulting in widespread problems of coastal pollution and conflicts between aquaculture and other interests such as tourist development and coastal ship traffic (e.g. Hong Kong, Singapore, Thailand). There is thus growing interest in moving production offshore. Offshore cages, however, are large and expensive and, while appropriate for salmonids and yellowtail, are untested for tropical marine species, many of which are sold live and in relatively small numbers (Beveridge 1996).

As stressed above, aquaculture is dependent upon a wide range of environmental goods and services, the more intensive the operation the greater the demands that are made. Lack of education about these relationships is part of the problem. Recent research has been responsible for a range of technological and management innovations – low-pollution feeds and novel self-feeding systems, lower stocking densities, vaccines, waste treatment facilities – which have helped reduce demands on the environment. However, such measures are unlikely to be adopted unless either imposed on industry or shown to increase profits. Novel feeds and feeding systems have been voluntarily adopted by the salmon industry in Scotland over the past 5 years, significantly improving feed conversion ratio (FCR) values and increasing profitability while reducing wastes (Beveridge *et al.* 1997). There is increasing adoption of 'polluter pays' policies by regulatory authorities in some western countries in which licences to discharge wastes and monitoring are used to control discharges (Beveridge *et al.* 1994).

While some argue that the state should not stifle economic growth through over-regulation, the environment is an issue of growing importance to consumers in Europe, North America and Japan, increasingly unwilling to buy food without regard to how it has been produced (Phillips 1994; Rackham 1995). To satisfy both consumers' aspirations and legal obligations with regard to food safety, retailers are beginning to seek products that are produced under strict quality assurance schemes such as HACCP and ISO 9000 (Aukrust, Wesenberg & Slinde 1995). Environmental management schemes and environmental auditing procedures, in which the impacts associated with aquaculture production are identified and the mitigative measures to minimize these impacts are put in place and carried out, are beginning to be adopted by sectors of the industry

(Gavine, Rennis & Windmill 1996). Thus, one may expect to see increasing market-related factors and consumer perceptions affecting the production and environmental management of aquaculture farms in Asian countries, particularly those producing products for export markets.

It should also be recognized, that while the negative environmental impacts of aquaculture have received considerable attention of late, aquaculture is contributing to environmental improvement and conservation in many ways, such as through small-scale integrated farming systems, conservation of species and water-quality improvement in coastal waters. It is also increasingly needed to meet growing demand for aquatic foods, which cannot be met by static or declining capture fisheries yields. Because many of the environmental problems caused by aquaculture can be dealt with through improved management – at various levels from the farm through to watershed or shared coastal area, and at local, national and regional levels – the challenge will be to fully integrate an improved understanding of environmental interactions of aquaculture systems and their management with the further development and promotion of systems that enhance food security and social and economic development. Research clearly has an important role to play in this process.

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